Perceived consonance of harmonic intervals in 19-tone equal temperament

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Background in microtonal research. Regardless of the method of evaluation used, the 19-tone equal temperament (19-tet) has frequently emerged as one of the most plausible candidates for an alternative equally tempered tuning system (e.g. Krantz & Douthett, 1994). Speculations on consonance within the 19-tet have been presented by Yasser (1975/1932) and Mandelbaum (1961).

Background in psychoacoustics. According to Plomp and Levelt (1965), sensory consonance for harmonic complex tones reaches its local maxima at simple-integer frequency ratios (which represent the consonant intervals). These ratios are well approximated in e.g. 12-tet and 19-tet. Quite similar influence of coinciding and nearly coinciding partials can also be found for inharmonic tones (cf. e.g. Geary, 1980). Terhardt (1984/1976) suggested that sensory consonance is insufficient to describe the phenomenon of *musical consonance*, which also depends on culturally conditioned aspects of music.

Aims. The present study had two aims. First, we wanted to get a comprehensive overview of the relative amounts of consonance and dissonance perceived among the harmonic intervals of 19-tone equal temperament. Second, we aimed at producing general information about the strategies that are used for making judgments concerning musical consonance (e.g. the influence of fundamental frequency ratios vs. the matching of partials). This involved evaluating how well current models of sensory (or tonal) consonance would predict the experimentally obtained values of this study.

Method. Two experiments were conducted in order to study listeners' tendencies to attribute patterns of relative consonance and dissonance to adjacent harmonic intervals of the 19-tet. The stimuli in Experiment 1 consisted of ordered pairs of harmonic intervals. The subjects indicated whether the perceived consonance increased or decreased from the first to the second interval. Experiment 2 was designed firstly to replicate the previous findings in an a-temporal setting: now the subjects had to choose the most consonant interval from three alternatives that they were free to explore using three push-buttons. In half of the trials, Experiment 2 also incorporated inharmonic spectra, designed to yield maximum sensory consonance for intervals that would otherwise be heard as dissonant.

Results. The results suggest that (1) intervals, which approximate the familiar diatonic intervals, were perceived as most consonant. (2) The subjects used various strategies in their judgment on consonance of harmonic intervals: sensory consonance, fundamental-frequency relations and avoidance of slow beating were all significant factors. Sensory consonance seemed to be the dominating factor when subjects judged dyads incorporating an inharmonic spectrum. These findings do not support the previously proposed hypothetical consonance/dissonance rankings for 19-tet (by e.g. Yasser).

Conclusions. Although unsatisfactory in itself to describe *musical consonance* in 19-tet, the results obtained in this study will provide a psychoacoustic foundation for such a concept. As Huron (1994) has noted, there exists a connection between sensory aspects of consonance and most common musical scales and chords. Thus, our results will form a basis for practical suggestions concerning the *use* of the 19-tet.

Introduction

Thousands of pages have been devoted to promote various microtonal systems. The quantity of proposed systems is almost as great as the number of inquiries written. However, only few experimental studies on microtonal systems have been carried out. In the present experiment, the point of departure was to choose one specific tone system, and to investigate the subjects' preferences and perceptions within that particular system. Among the alternative equal divisions of the octave, the 19-tet is one of the most celebrated. Speculative music-theoretical studies devoted to 19-fold divisions of the octave include the studies of Yasser (1932) and Mandelbaum (1961). Apart from a recent study by Huovinen (2003) concerning the categorical perception of melodic intervals within the 19-tet, however, not much attention has been paid to the system in the literature on music perception and cognition.

The 19-tet has some interesting basic qualities: (1) it has a manageable number of pitch classes; (2) it is *not* related to the 12-tet simply by division of the familiar semitone into smaller units; (3) it has some acoustic and structural qualities that are potentially helpful from a perceptual point of view. For one thing, if we assign pitch-class numbers 0 through 18 to the 19 pitch-classes of the system, we will be able to form a diatonic scale that, starting from pitch-class 0, comprises pitch-classes 0, 3, 6, 8, 11, 14, and 17 (cf. Huovinen, 2003). For another, the 19-tet provides more accurate approximations for the pure thirds (315.6 and 386.3 cents) than 12-tet. In fact, the 19-tet version of minor third is almost perfect (cf. Table 1). In general, the 19-tet seems to be among those systems that have most frequently emerged as plausible candidates for an alternative equal temperament, regardless of the method of evaluation (e.g. Krantz & Douthett, 1994).

In the following, the intervals of the 19-tet will be referred to by using abbreviations such as "int6" (= the major third) and "int11" (= the perfect fifth), where the numbers indicate the number of smallest intervallic units of the system (one unit being 63.2 cents).

19-tet interval	**Size (cent)**	**19-tet interval**	**Size (cent)**
0	0	**13**	821.1
1	63.2	**14**	884.2
2	126.4	**15**	947.4
3	189.5	**16**	1010.5
4	252.6	**17**	1073.7
5	315.8	**18**	1136.8
6	378.9	**19**	1200
7	442.1	**20**	1263.2
8	505.3	**21**	1326.4
9	568.4	**22**	1389.5
10	631.6	**23**	1452.6
11	694.7	**24**	1515.8
12	757.9	**25**	1578.9

Table 1: Intervals of 19-tone equal temperament

Experiment 1

The primary purpose of the present experiments was to locate points of relative consonance and dissonance within the range of harmonic (simultaneous) intervals provided by the 19-tet. It was thought that this could be achieved in a musically relevant manner by applying the concept of dissonance resolution. In traditional harmonic theory, dissonant harmonic intervals are standardly resolved by letting either one or two of the pitches move stepwise so as to produce a more consonant interval. To the extent that the music-theoretical concept of intervallic dissonance is primarily understood in relation to such common compositional resources, it emphasizes the local character of dissonance: dissonant intervals are dissonant primarily relative to their nearest more consonant neighbours. In this respect, traditional tonal theory does not encourage a complete ranking list of harmonic intervals in terms of relative consonance and dissonance. In many discussions of dissonance treatment, the question of the relative dissonance of, say, the tritone and the minor ninth does not even rise. What is musically important for the tritone is its relative dissonance with respect to its immediate neighbours, the perfect fourth and the fifth; similarly, the minor ninth only needs to be compared to the one consonant interval that it typically resolves to, the octave.

These considerations suggest that a musically relevant way of exploring the experience of intervallic consonance and dissonance in a microtonal setting would be to simulate typical resolutions of dissonance by applying stepwise alterations to each interval type available. Given the local character of musical dissonance, we should be able to learn quite a lot about the dissonance characteristics of a given microtonal system only by seeing whether such "resolutions" would indeed be heard as such by musically competent listeners. In Experiment 1, we thus wanted to produce an overall view of typical judgments of increase and decrease (resolution) of dissonance within the repertoire of harmonic intervals of the 19-tet.

As the 19-tet provides relatively good approximations for most of the familiar diatonic intervals, some predictions concerning the favored resolution intervals were easy to make. For instance, the perfect fifth of the system would, despite its slight out-of-tuneness (694.7 cents), probably be heard as more consonant than its neighbours. Such expected findings would be valuable mainly for comparison with respect to the more interesting cases, although one could use them to argue against Yasser's (1975/1932) eccentric views regarding consonance and dissonance in a 19-fold division of the octave. More importantly, however, even some of the familiar diatonic intervals could shed more light on the relative merits of pure intonation and learned consonance paradigms. In the 19-tet, the minor third (int5, 315.8 cents) is almost as pure as it could be, whereas its neighbour, the major third (int6, 378.9 cents) deviates slightly more from its pure counterpart. However, in addition to the fact that the major third figures heavily in learned tonal schemas as a paradigmatic consonant interval, the int6 of the 19-tet also exhibits a high sensory consonance when considered as consisting of harmonic complex tones. With respect to the spectrum used for the present experiment, int6 should actually exhibit a higher sensory consonance of the two (cf. Figure 2 below). The comparison of such intervals could potentially be used to decide between hypotheses concerning the strategies employed in consonance judgments. Finally, there was the question of other possible consonances besides the common diatonic ones. Could we find other points of relative consonance between the known diatonic consonances, or does the diatonic scale exhaust the consonant intervals for normal Western listeners even in such a setting of relative judgments?

Method

Subjects. There were 31 participants, all of whom were students of musicology at the University of Turku, Finland. They average age was 23.6 years (SD = 5.2), and they had been actively engaged with music for an average of 14.3 years (SD = 4.0). On average, they had received formal training in a musical instrument or in singing for 10.3 years (SD = 5.4), and attended lessons in music theory, ear training or related subjects for 5.7 years (SD = 4.5). Two of the subjects reported having absolute pitch.

Apparatus. The preparation of the stimuli as well as the experiment itself was carried out using a Power Macintosh G4 computer. The stimuli were generated with the sound synthesis program csound, and the experiment was run using the SuperLab experimental laboratory program. The signals were played through a pair of Sony MDR-P180 headphones.

Stimuli. The stimuli consisted in pairs of successive harmonic intervals, each of the two intervals in a pair always having the duration of 2 s (with a linear onset of 10 ms and a decay of 100 ms). In the experiment, the first of the two harmonic intervals, the *basic interval*, could range from 63.2 through 1572.9 cents with 63.2-cent increments, thus representing all 19-tet intervals from int1 through int25 (int25 = a major 10th.) The second harmonic interval, the *deviant interval*, was either larger or smaller than the basic interval, differing from it by either one or two smallest 19-tet units in either direction. The change was effected simply by letting one of the pitches in the basic interval move up or down by int1 (63.2 cents) or int2 (126.3 cents) and holding the other pitch constant. The experiment thus had a design consisting of 25 basic intervals and, for each of them, deviations of two possible magnitudes (one/two units of 19-tet), in two possible directions (up/down), in either of the two voices (upper/lower tones of the intervals). Given two impossible deviations (when the basic interval was int1), there were 198 trials in all.

The stimulus intervals were composed of tones that consisted in the 10 first partials of a sawtooth wave. For each trial, the pitch level of the basic interval was determined by setting the average of its two (virtual) pitches to middle C (corresponding to 261.6 Hz).

Procedure. The 198 trials were divided into three randomized blocks, using basic intervals 17–25 for the first, 9–16 for the second, and 1–8 for the third block. Each subject was required to complete the three blocks in this order during one session, working alone with the computer according to written instructions. The task of the subjects was to listen to each pair of harmonic intervals and indicate using the plus and minus keys of the computer whether they felt that there was an increase ("+") or a decrease ("–") in consonance from the first to the second interval (that is, from the basic interval to the deviant interval). The next trial was automatically triggered by the response. There were three practice trials that could also be used to set a comfortable volume level. Between the three blocks there were short breaks during which the subjects had to save their work. The whole experiment could be completed in circa 45 minutes.

Results and discussion

We present the results of Experiment 1 as the percentage of resolution judgments for each size of the deviant interval. For each interval type, we thus observe all trials that were terminated by this interval and report the percentage of such trials that were given "+" as response. This may be understood as a relative measure of local consonance. If a certain interval yields the value 90%, for instance, it means that it has mostly been judged as an appropriate resolution for a more dissonant intervallic situation when heard after one of two smaller neighbours or one of the two larger ones. These results are shown in figure 1.

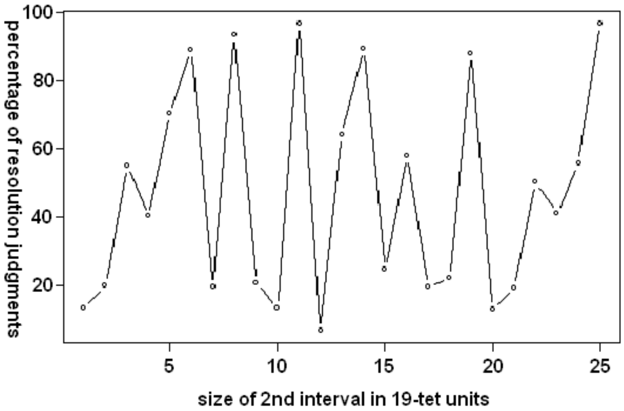

Figure 1. The results of Experiment 1: percentage of resolution judgments as a function of the size of the deviant interval.

One strikingly clear feature of figure 1 is the negative verdict it returns for the idea of non-diatonic points of relative consonance. The peaks occur invariably at diatonic intervals whereas all the non-diatonic ones peculiar to 19-tet have values below 25%, with the sole exceptions of int4 and its octave compound, int23. For instance, neither of the tritones (int9, int10) has apparently been consistently judged more consonant than the other one. As both of these intervals (568.4 and 631.6 cents) fall at equal distances from our familiar 12-tet tritone of 600 cents, we may conclude that slight differences of intonation would not deprive the tritone of its status as a point of local relative dissonance. On the other hand, at locations in which reasonable approximations of possible diatonic intervals have not been available, there is simply a gap in the resolution judgments. Such a situation presents itself at the areas where we would normally expect to find the minor 2nd, its inversion (the major 7th), and its octave compound (minor 9th). Here we may see that, for instance, neither of the possible contenders for the major 7th status, int17 (1073.7 cents) and int18 (1136.8 cents), have succeeded as points of relative resolution.

We also see that the beginning of the second octave (at intervals 20 through 25) clearly resembles the beginning of the first one (at intervals 1 through 6). This suggests an unexpectedly high degree of consistency in dealing with octave-compounded versions of (partly) unfamiliar intervals. In both octaves, the major 3rd (int6 and int25) has acquired a value higher than the minor 3rd (int5 and int24). This might come as surprise for those who have expected the extremely good approximation of the just minor 3rd to operate as an important structural interval in the 19-tet (see, *e.g.*, Mandelbaum, 1961).

Another feature that relates to the minor 3rd is the relatively high value (40.2%) of int4, which at 252.6 cents should be exactly between two familiar diatonic intervals. Given that its two larger neighbours have themselves been among the accepted resolution intervals, it follows that int4 must have acquired its "+"-responses in comparison with its two lower neighbours, int2 and int3. The latter of these being a decent approximation (189.5 cents) of a familiar major 2nd, we may hypothesize that some subjects have heard int4 as categorically different from the major 2nd, that is, probably in some sense as a minor 3rd. The same interpretation applies to the octave-compounded versions. If this is correct, it demonstrates the interconnectedness of consonance judgments and the categorical perception of intervals: the perceived consonance of an interval not only depends on the relative sensory consonance of the surrounding intervals, but also on the possibility of imputing learned categorical distinctions on this set of intervals. On such a hearing, even an unfamiliar interval such as int4 might serve as a "third" in distinction to its lower neighbours, and be allowed the status of a consonance by virtue of this categorical judgment.

Experiment 2

Experiment 2 was designed firstly to replicate the previous findings in an even less "musical" setting. This involved eliminating both the fixed temporal succession of the intervals and the common tone between them, which jointly made it possible for the subjects in Experiment 1 to musically interpret the stimuli as typical contrapuntal situations (e.g., resolutions of dissonance). Thus, another experiment was needed in order to be able to evaluate the importance of purely sensory factors for the judgements. It was thought that this would be achieved by giving the participants a more active role than in the previous experiment: they would be given a set of push-buttons on which the stimulus intervals could be "played" in a any desired order. Thus, the experimental setting was to resemble more the tuning of an instrument than normal music listening. Because of the relative redundancy in the results of Experiment 1 with respect to the two octaves, the octave-compounded intervals were now excluded.

In half of the trials, Experiment 2 also incorporated inharmonic spectra, designed to yield maximum sensory consonance for intervals that would otherwise be heard as dissonant.

Method

Subjects. 22 musically trained subjects aged between 15 and 57 (M = 32.0, SD = 11.9) were tested. 11 of them were professional musicians and others were more or less actively involved with music as their hobby. Subjects had, on average, 17.3 years (SD = 13.7) of experience in a playing musical instrument. They had studied music theory or ear training on average 5.9 years (SD = 4.7). Two subjects reported having absolute pitch.

Apparatus. Stimuli were created by means of additional synthesis using Music Experiment Development System (MEDS 2002-B-1) software[1], and were further edited using waveform editor GoldWave. The stimuli were on wave-format (i.e. they were .wav-files). The experiment was realised in Internet Explorer 6 –environment on laptop computer (Fujitsu-Siemens Amilo) with additional loudspeakers (JBL Pro).

Stimuli. Once again, the stimuli were the harmonic (simultaneous) intervals of 19-tet**.** In Experiment 2, two different sounds were used: Sound 1 was similar to that used in Experiment 1 (10 first harmonic partials with amplitudes relative to 1/*n*). Figure 2 presents the predicted sensory consonance for Sound 1. The second sound (Sound 2) consisted of eight (both harmonic and inharmonic) partials with amplitudes relative to 1/*n*. The spectrum was designed by using the method of Sethares (1998). The frequencies of the partials are *f*, 2*f*, 2.8805*f*, 4f, 4.6284*f*, 5.761*f*, 8*f*, and 10.3275*f* (where *f* is the fundamental frequency of the tone). The predicted sensory consonance for Sound 2 is presented in Figure 3. The sound-pressure levels were equal for both tones of the intervals. The duration of each stimulus interval was 1 s; onset was set to 10 ms and decay to 100 ms. The duration and the temporal envelope were the same for both sounds.

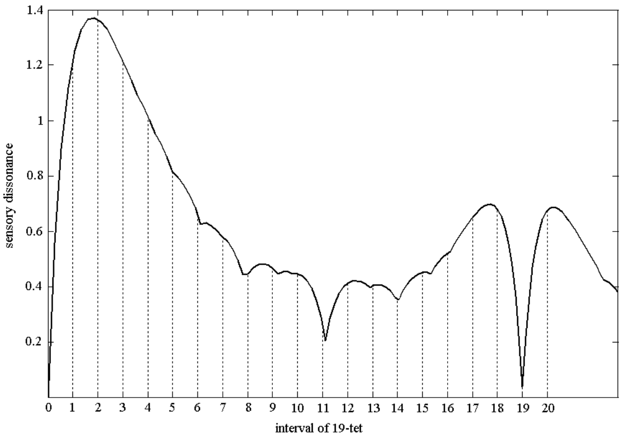

Figure 2: The predicted sensory dissonance of Sound 1 according the model of Plomp & Levelt (1965) (fundamental frequency: 261.63 Hz). Created using matlab-program written by Sethares (1999, p. 301).

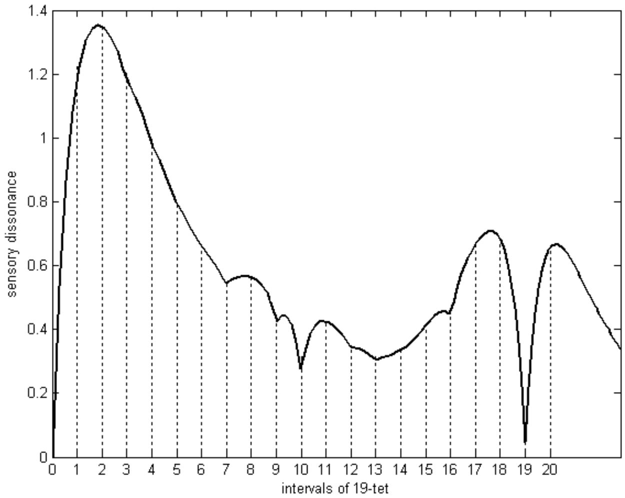

Figure 3. The predicted sensory dissonance of Sound 2 according the model of Plomp & Levelt (fundamental frequency: 261.63 Hz). Created using matlab-program written by Sethares (1999, p. 301).

Procedure. The stimuli were arranged in groups of three adjacent intervals of the 19-tet so that the middle interval within each varied between 1-19. For instance, intervallic combination no. 6 included intervals int5, int6, and int7. Intervals were presented in three different transpositions in the vicinity of middle C (261.63 Hz): non-scale increments of 40 cents for the lower tones of the intervals were used. As a result, the fundamental frequencies of the lower tones were 255.65 Hz (C – 40 cents), 261.63 Hz (C), and 267.74 Hz (C + 40 cents) respectively. Each group included one interval in each transposition. Consequently, the pitch relationships between the three intervals of a group were quasi-arbitrary, and not governed by the 19-tet system as they had been in Experiment 1. In the experimental setting, each group of intervals corresponded to a visual display of three adjacent push-buttons. The order of presentation for groups of intervals, the order of the intervals within the visual display, and the order of transpositions within groups were all randomized. Each subject heard each group of intervals in three different combinations of transposition and visual order. In a sense, the subjects enhanced the randomization: they were not instructed to push the buttons in any particular order.

In each trial, the subjects were asked to choose the most consonant interval from the three alternatives. They were instructed to freely explore the unlabelled push-buttons, and they were able to play each interval as many times as they wanted to. Each subject performed 2 (sounds) x 19 (intervallic combinations) x 3 (combinations of transposition and visual order) = 114 judgments within the groups of three intervals. The duration of the session varied from 25 to 60 minutes.

Results and discussion

Sound 1. The results concerning Sound 1 are presented in Figure 4. The results are presented as percentages of such responses in which the interval was rated as the most consonant one among the three intervals in a combination. The dominance of the familiar diatonic intervals in the evaluations of consonance was even more undisputable than in Experiment 1. None of the non-diatonic intervals obtained value higher than 20%. Again, similarly as in Experiment 1, int4 was the most frequently picked non-diatonic interval. As Figure 4 indicates, the results for most of the intervals were quite similar to Experiment 1. However, one strikingly different feature was found: int5 was now perceived significantly more consonant than int6. The same tendency was detectable even more clearly with the inversions of these intervals: int14 was rated significantly more consonant than int13. The greater magnitude of the effect in this case might be due to the fact that unlike int5, int14 represents a higher predicted sensory consonance with respect to its neighbour as well as a more accurate approximation to the appropriate just interval (5/3).

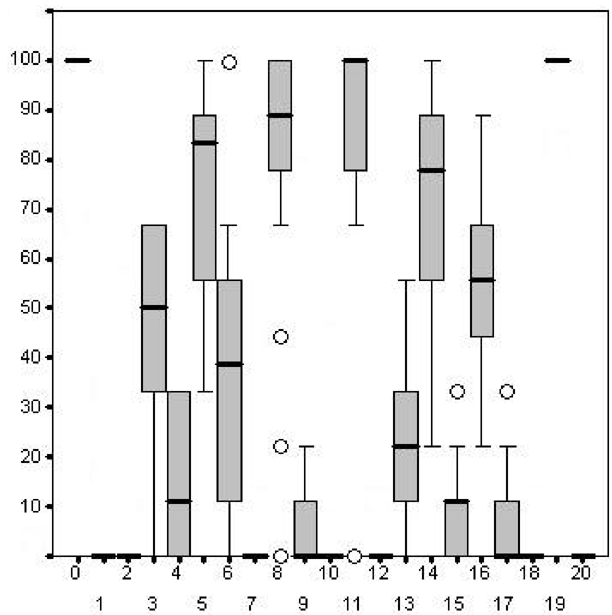

Figure 4. The results of Experiment 2, Sound 1: percentages of "most consonant" –responses. (o = outliers, extremes are excluded).

These are the findings one would expect given that int5 and int14 provide very accurate approximations for their just intoned counterparts. In addition, int5 and int14 might sound more familiar than int6 and int13, because deviation from 12-tet is smaller.

The differences between Experiment 1 and Experiment 2 concerning the values of perceived consonance of int5 and int6 could be (partly, at least) explained by the designs of the experiments. For instance, given that the minor third (int5) and its inversion, the major sixth (int14) were clearly preferred to their modal variants (int6 and int13) in Experiment 2, we may see that in the more "musical" context of Experiment 1, only the thirds were perceived differently. It may be that the more "musical" relationships have in that case activated learned top-down strategies in which the major third has figured as a paradigmatic consonance. Such strategies could then have overridden any other, more direct perceptual strategies. In Experiment 2, such top-down strategies have not been available, because it has been much more difficult to relate the individual stimuli to each other musically. Another possible explanation is that in Experiment 1 subjects were forced to perform their evaluations on with respect to quickly passing stimuli. As a result, the judgments were probably based more on learned intervallic schemas (which directed the judgment towards int6). On the other hand, in Experiment 2 (although the duration of stimulus intervals was shorter than in Exp. 1) subjects were allowed to compare intervals more freely by clicking the push-buttons. This arrangement probably enabled the use of more stimulus-oriented strategies (which probably directed the judgments towards int5).

Sound 2. The results for harmonic intervals presented with Sound 2 are presented in Figure 5 as percentages of such responses in which the interval has been rated as the most consonant of intervallic combination. In general, subjects have been able to recognize the major minima of predicted sensory dissonance (cf. Fig. 3): int7, int10, and int13 were frequently chosen. Surprisingly, int5 was again frequently rated as consonant. The most consonant intervals of Sound 1, intervals int8 and int11 were now clearly perceived as dissonances.

Most subjects were not as consistent in their judgments with Sound 2 as with Sound 1. The main reasons for this inconsistency were probably (1) the unfamiliarity of the timbre and (2) the conflicting cues (i.e. matching of the partials vs. familiar ratio of fundamentals). We shall later return to this discrepancy. In general, the differences on perceived consonance of the intervals were not as clear as with Sound 1. For most subjects, there were neither very consonant nor very dissonant intervals. These values on perceived consonance would be disadvantageous for musical styles in which the degree of consonance and dissonance is varied in a meaningful way (cf. Sundberg, 1991, p. 85).

The model used in this study to predict the sensory consonance failed to predict the differences between two sounds used in Experiment 2. The differences between relatively consonant and relatively dissonant intervals were found to be larger with Sound 1. Similar effect cannot be found in Figures 2 and 3. The probable explanation is that even on unmusical task like this, the music-specific factors (which Terhardt (1984 calls as *harmony*) are involved.

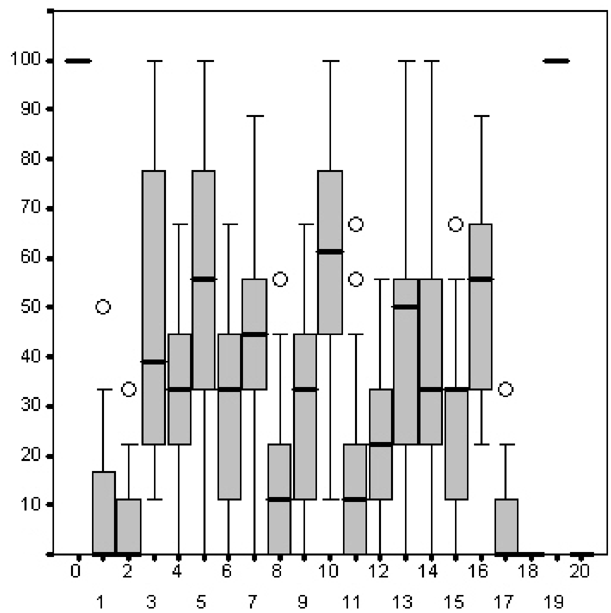

Figure 5: The results of Experiment 2, Sound 2: percentages of "most consonant" –responses. o = outliers, extremes are excluded.

Subjective strategies. With respect to Sound 1, most subjects were highly consistent in their responses. However, intersubjective differences suggest that subjects utilize different strategies in their judgments. Since the consonant intervals of 12-tet exhibit high sensory consonance (and this is also true concerning the diatonic intervals of the 19-tet), both strategies lead to quite similar results in the case of Sound 1. However, the responses differed significantly for some intervallic combinations. For example, 15 subjects out of 22 were perfectly consistent with respect to combination no. 3 (int2, int3, and int4). Regarding this combination, significant differences were found between subjects: eight subjects out of the 15 picked int4 and other seven perceived int3 as the most consonant. A possible explanation for these divergent evaluations is that int4 has higher sensory consonance but int3 sounds more familiar (differing only 10.5 cents from major second of the 12-tet). In accordance with such intuitions, we thus defined two strategies, the "sensory consonance strategy" and the "familiar fundamental ratio strategy" in order to find out which strategy is the more suitable to explain the subjects' responses. For each subject we subsequently determined the relative frequencies of choices such that corresponded to the highest predicted sensory consonance within an intervallic combination (the sensory consonance strategy) and to the closest approximation to a 12-tet interval that could be achieved within a combination (the familiar fundamental ratio strategy). Regarding Sound 1, 20 subjects out of 22 reached a highly significant level (p = .001) regarding the sensory consonance strategy. For the familiar fundamental ratio strategy, 19 subjects reached a highly significant level.

For one of the most musically trained participants, the responses (with respect to Sound 1) did not fit in either strategy: he did not pick int6, int8, or int11 in any of the combinations in which they occurred. In addition, he did choose int5 and int14 always when it was possible. For this subject, the 19-tet versions of the major third, fourth and fifth (which are slightly out-of-tune) clearly were not acceptable. However, the choices that he preferred over int8 and int11 were not consistent: clearly his strategy was just to avoid these out-of-tune intervals. Thus, the avoidance of slow beating might be regarded as a third strategy used in this experiment to evaluate the consonance of musical intervals.

Sound 2 provides more information with regard to such subjective strategies. The results concerning perceived consonance of harmonic intervals in Sound 2 indicate the primary importance of sensory strategies for tasks such as the present one. Concerning the "sensory consonance strategy", six subjects out of 22 reached the critical limit (27/48) at level p = .001.[2] 14 subjects reached the critical limit (24/48) at level p = .01. Familiar fundamental frequency sizes were not as crucial for Sound 2: only one subject clearly used this strategy reaching the critical limit at level p= .01. The "avoidance of beating strategy" was not successful with respect to Sound 2, because the "consonant" intervals performed in Sound 2 do not produce slow beats.

The surprising finding was that the use of sensory consonance strategy with Sound 1 did not correlate with the use sc-strategy with Sound 2. Similar findings with other strategies suggest that subjects clearly did not depend on one specific strategy. In the subjects' judgments on consonance several strategies function in dynamic interaction. The most unanimous results tended to occur when the several strategies pointed to the same direction.

Conclusions

Our results do not support the consonance/dissonance rankings presented by Yasser (1975/1932).[3] In fact, our findings concerning perceived consonance of sounds with harmonic spectrum proved to be quite opposite. Responses more similar to Yasser's predictions might possibly be achieved using even more extreme manipulations of spectral content than the one that we applied in Experiment 2. Of course, this would also mean discarding all timbres that are even remotely reminiscent of existing acoustic instruments.

In a fundamental sense, the phenomenon of consonance does not exist *a priori*. The consonance and dissonance are not just properties of intervals and their spectral attributes: they are also functions of musical contexts and—most importantly—of people who are involved with music; people who are making sense of music. Different strategies used successfully by subjects were clear indications of this. Previously, it has been shown that the strategies of tonality perception may vary between individuals who nevertheless may remain consistent in the application of their own personal listening strategies (Huovinen, 2002). Our present findings indicate that individual consistency and intersubjective variability of strategy may also co-occur in such (arguably more bottom-up) contexts as the perception of consonance and dissonance.

For these reasons it was not necessary, not even appropriate, to try predicting the perception of hypothetical listeners who would be accustomed to the 19-tet (or, try to get rid of bias caused by a lifetime of exposure to the 12-tet). Potential listeners of music that utilizes alternative tone systems will most probably be ones who also have already been accustomed to the 12-tet.

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[1] Designed and programmed by Roger A. Kendall, Music Perception and Musical Acoustics Laboratory (MPAL), UCLA.

[2] Interval combinations with primes (int0) and octaves (int19) were excluded as trivial.

[3] Yasser's rationale for defining consonances and dissonances within the 19-tet goes approximately as follows: he defines the basic consonant chords of the 19-tet as "logical" successors of previous basic consonant chords (such as the major triad), and then derives the consonant intervals from their intervallic content (Yasser, 1975/1932, pp. 169-172). After defining the basic consonant chord of 19-tone system, Yasser claims that this chord "by its very nature comprises—as a rule—all the consonances, and absolutely excludes all the dissonances" (Yasser 1975, p. 172). As a consequence of this assertion, the consonant intervals would be 3, 4, 6, 7, 9, 10, 12, 13, 15, and 16. Consequently, the dissonant ones would be 1, 2, 5, 8, 11, 14, 17, and 18, including the minor third and the major sixth as well as the perfect fourth and fifth!